

# Coral farming: past, present and future trends

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## ABSTRACT

There have been significant technical advances in marine aquarium maintenance in the last 20 years. It is now possible to maintain, grow and reproduce in aquaria many of the coral species found on coral reefs. Due to the increased demand for live corals and other reef invertebrates, the commercial production of these organisms for the home aquarium market has become feasible. This paper describes the early beginnings of live coral propagation, current coral propagation facilities located in Europe, North America, and the Pacific basin followed by a discussion of an example of the possible future for coral farming, namely propagation by sexual reproduction. Suggestions for areas of further research in captive coral propagation are also presented.

## INTRODUCTION

Since the late 1980s, the popularity of home aquariums that contain living corals has increased dramatically. The global trade in live stony coral has increased from approximately 20 t per year over 1985–1989, to over 400 t per year by 1995 (Green and Shirley, 1999). Prior to 1986, the keeping of live coral aquaria was confined mainly to Europe, specifically Germany, Austria, Belgium, the Netherlands and Scandinavia. In 1986, a series of popular articles appeared in the hobbyist magazine *Freshwater and Marine Aquarium*, which had a profound affect on the marine aquarium hobby in North America and its associated industries (Smit, 1986). Written by George (Geert) Smit, these articles outlined the workings and philosophy behind a method of European aquarium keeping known as a 'mini-reef'. These articles fueled a renaissance within the North American marine aquarium hobby, resulting in a greater demand for not only live corals, but also live rock and marine fish previously rarely imported due to low demand. The resulting popularity of these systems has resulted in the United States becoming the leading importer of coral reef animals in the world (Green and Shirley, 1999). Improved shipping techniques and materials, better flight connections and a greater number of exporters/importers has also helped to fuel the increased availability of reef animals in North America.

Although there was an explosion in interest in minireef aquariums in North America after 1986, it is generally felt that this interest has peaked and a steady decline in sales in this industry has been noted since approximately 1995 (M. Paletta, advanced aquarium hobbyist, USA, pers. comm.). Imports of live corals have also shown declines since 1995 (Green and Shirley, 1999). The reasons for this are unclear, however the high cost of the equipment and animals,

coupled with the level of expertise and dedication required to run these systems successfully over the long term, may have contributed to the observed decrease. The decline in interest may also be coupled with the corresponding increase in popularity of home computers and other technologies, competing for consumer attention and dollars.

As a result of the increased trade in live coral over the last ten years, concern has been raised about the impact of coral removal on native reefs, and the possibility of localized extinction of slower growing coral genera. In light of the increased frequency of coral bleaching events and the severe bleaching event of 1997/1998, there are now concerns that coral reefs may no longer be able to withstand harvesting of live coral for the marine aquarium trade. It is worth noting, however, that the collection of live coral for the dried curio trade and for the manufacturing of lime and building materials, consumes magnitudes more coral tonnage per year than the aquarium trade. For example, 25,000 t of coral is mined for construction materials in the Maldives in a single year (Brown and Dunne, 1988). Compare this to the estimated 2000 t of live coral that has been traded globally from 1985 to 1997 (Green and Shirley, 1999). However, the taking of live coral for the aquarium hobby seems to have attracted the greatest amount of attention. In response to this, several government and non-government organization (NGO) funded programs and private companies have appeared in the last few years. The aims of these programs and companies are to supply the aquarium hobby with artificially propagated corals to offset the wild collection of live coral, and to provide reasonable livelihoods for native peoples who own or are employed on the coral farms. This paper will review the past history of coral propagation for commercial and other purposes, examine some of the present programs operating, and offer a view of what the future may hold for sources of captive raised corals for the aquarium hobby.

### *The past*

Perhaps the earliest work on coral propagation was done at the Noumea Aquarium in New Caledonia. As far back as 1956 this aquarium has displayed live field-collected corals that were maintained *ex-situ* in open systems exposed to direct sunlight (Carlson, 1999). Its director, Dr. Rene Catala, developed techniques in the early 1960s for propagating *Acropora* and other stony corals (Catala, 1964). Elsewhere, the Waikiki Aquarium and the Monaco Aquarium began displaying live corals in the mid- to late-1970s. These aquarium systems were dependent on a continuous supply of natural seawater and thus the aquarium seawater conditions were not much different from the adjacent ocean (Carlson, 1999). In the early 1980s the Waikiki Aquarium began fragmenting its branching stony corals and became the first public aquarium in the United States to propagate coral for use in its exhibits and to supply other public aquaria in North America with coral fragments. Today this aquarium has over 170 species of stony and soft corals in its collection.

European hobbyists have long known that many of the corals in the aquarium trade can be readily propagated by asexual means. German hobbyist Peter Wilkens wrote as far back as 1973 about the ability to propagate both stony and soft corals (Wilkens, 1973, 1990). In the early 1980s in Berlin, West Germany, hobbyist Dietrich Stüber received a live rock that contained a small projection of stony coral that was subsequently identified as *Acropora* sp. From this single colony Stüber was able to fragment and distribute over 1000 pieces to hobbyists during the 1980s and 90s (Stüber, advanced aquarium hobbyist, Germany, pers. comm.). It is interesting to note that, while asexual propagation of *Acropora* was occurring in Europe, it was not uncommon to hear coral scientists in North America claiming that these corals were impossible to keep alive in captivity, let alone grow and propagate. Also during this time it was not unusual for hobbyists to exchange cuttings of soft and stony corals not only with each other, but also to bring their excess cuttings to retailers and exchange these for goods. Some species (e.g. *Xenia* spp.) grew so quickly and became so widely exchanged that many stores stopped accepting them from hobbyists. Several public aquaria in Germany also displayed living corals (e.g. Loebecke Aquarium, Dusseldorf, Germany) (J. Sprung, advanced hobbyist, USA, pers. comm.), many of which were donations from hobbyists. By the late 1980s it was not uncommon for public aquariums to have live coral displays consisting entirely of donated pieces from propagated colonies (e.g. Bochum Tierpark, Bochum, Germany) (J. Sprung, advanced hobbyist, USA, pers. comm. ).

Exporters of corals from Asia have also long known about the harvest potential offered by asexual reproduction of anthozoans. In order to cut down on travel time to and from collection sites, collectors often transplant colonies of corallimorpharians and zoanths to sites close to their holding facilities. This would allow for the rapid collection and transport of specimens to the holding facility (Wilkens, 1990).

In the early 1960s the first commercial coral propagation facility in North America, Tropicorium Inc., appeared in Romulus, Michigan. This facility consists of a large, glass-roofed greenhouse attached to the back of the owner's house. Several large wooden tanks were constructed, lined with plastic and filled with coral aggregate as a substratum. Several hundred heads of live stony and soft corals were imported and placed into these tanks. By fragmenting larger heads into smaller pieces, this facility was able to generate numerous fragments. Some of these were sold and others were allowed to grow-out to produce mother colonies for further fragmentation. Although imports of new corals were frequent, much of what was sold to hobbyists was fragmented coral.

Numerous other small-scale operations appeared in the early- to mid-1990s. These consist primarily of basement operations in hobbyist homes and are primarily designed to earn extra income for the hobbyist and not to serve as a major supplier of corals to the trade. A common practice (even more so today) was the exchange of fragments between hobbyists, and between hobbyists and retailers. These types of activities have greatly increased over recent years such that many hobbyist organizations now frequently hold raffles and auctions of propagated corals during club meetings and national conferences.

### *The present*

Several operations around the world are currently involved in the propagation of corals for the aquarium trade and for use in public displays. Those located in third world countries are primarily propagated *in-situ* while those in North America and Europe are primarily *ex-situ* cultures. Those involved in the commercial supply of propagated corals consist of either privately funded operations or those that operate through grants from government agencies and/or NGOs. Many of these operations are located in the source country such as the Philippines, Solomon Islands, Palau, Fiji, Marshall Islands and Japan, and involve the local residents as much as possible (J.C. Delbeek, Waikiki Aquarium, pers. obs.; S. Ellis, Aquaculture Extension Agency, Pohnpei, Federal States of Micronesia, pers. comm.; D. Palmer, coral exporter, Solomon Islands, pers. comm.; T. Heeger, University of San Carlos, Cebu, Philippines, pers. comm.). Most of these are designed to offer the locals an alternative livelihood and to provide an opportunity to utilize their resources in an environmentally friendly manner. Those operations that provide corals for public display primarily involve public aquariums in North America and Europe (J.C. Delbeek, Waikiki Aquarium, Honolulu, USA, pers. obs.).

### *Japan*

On the island of Ishigaki, in the Ryuku Islands of Japan, there is a small commercial coral farm (C.P. Farm). With the co-operation of the local and federal governments the farm was able to obtain permits to collect and culture local soft corals only, but will obtain permits to culture local stony corals shortly. Currently this operation consists of a small coral culture and holding facility located within Ishigaki City plus an *in-situ* location for coral transplants and grow-out. There are currently plans to construct a stony coral farm in the near future. Soft corals currently being propagated include *Clavularia*, *Dendronephthya*, *Pachyclavularia*, *Sarcophyton*, *Simularia* and *Xenia*. Each large piece collected is sliced into tiny pieces that are subsequently attached to small pebbles. Approximately 500 pieces/month are sold and 150 pieces/month are returned to the ocean. Less than half of the transplanted pieces are confirmed to survive and grow over the long term. Due to severe bleaching in this region in the summer of 1998, a purple color morph of a local nephthiid species was lost. Currently the only viable pieces of this form are found in C.P. Farm's propagation facility. Once the land farm is completed, C.P. Farm plans to start producing a total of 1200 pieces/month of hard and soft corals for sale to the domestic Japanese market (T. Adegawa, C.P. Farm, Ishigaki Island, Japan, pers. comm.).

### *Philippines*

In the Philippines there are a number of government and NGO initiatives to introduce coral farming techniques to the local fisherfolk. One such operation is under the direction of Dr. Thomas Heeger of the University of San Carlos in Cebu. In this program, the aim is to construct 300 coral fishery units (CFU), which consist

of small local *in-situ* coral farms tended by villagers. The purpose of these CFU is to provide up to 30,000 coral fragments per year to restore local reefs. Combined with ecotourism, the goal is to educate the local fisherfolk of the value of living coral reefs and the ecotourism benefits of reef restoration and coral farms. At present there are 186 CFU in operation and more than 15,000 fragments have already been produced (T. Heeger, pers. comm.). Initially, the primary customers for these fragments are local hotels who purchase them to help restore the reefs in front of their properties. An added side-benefit is that the number of fish species in the areas of the CFU has increased, providing a food source for local villages (T. Heeger, pers. comm.). It is not unlikely that as this program expands, and as permit restrictions are overcome, these fragments will also become available to the marine aquarium trade.

### *Central Pacific*

Throughout this region coral culture is in its infancy but is expanding through extension and research activities. In Pohnpei, Federated States of Micronesia (FSM), there is a demonstration farm for soft and hard corals at the Marine and Environmental Research Center of Pohnpei. This will be the site of a Center for Tropical and Subtropical Aquaculture (CTSA) sponsored research project in 2000 to look at optimum farming practices for four species of soft and four species of hard corals. The goal of this project is to determine simple fragmentation and attachment techniques for corals that can be easily transferred to the rural village level. There is also a manual, published by the CTSA, detailing soft coral propagation techniques, economics of coral aquaculture and the establishment of a facility (see Ellis and Sharron, 1999).

In the Marshall Islands, one commercial company (Mau Island Mariculture) is involved in the small-scale culture of *Sarcophyton* and *Sinularia* as well as some *Acropora* species. They are currently only selling about 100 pieces per month as their main effort is in giant clam culture for the marine aquarium industry and are one of the main suppliers of *Tridacna maxima* and *T. squamosa* to the aquarium industry (S. Ellis, Aquaculture Extension Agency, Pohnpei, FSM, pers. comm.).

The most successful operation in this region was located in the Republic of Palau, which was the site of the first commercial giant clam farm in the 1980s. Originally this farm produced clam meat for local consumption and the Japanese sushi market. The shells were used to make ashtrays and shirt buttons. However, it soon became apparent that more money could be made selling live cultured clams to the marine aquarium trade. As a result, smaller, more colorful species of tridacnids began to be targeted. In conjunction, soft corals also were cultivated for the aquarium trade. With a change in management, this operation fell into disrepair and its production of clams and soft corals had tailed off noticeably by the mid-90s. In 1997 a new company, Belau Aquaculture was formed that specialized in *in-situ* culture of soft corals for the aquarium market. At one time Belau Aquaculture was selling 1400 pieces of cultured soft coral per month (S. Ellis, Aquaculture Extension Agency, Pohnpei, FSM, pers. comm.). Unfortunately, a major bleaching event in

the summer of 1998 wiped out much of their stock. However, the company has recently moved to a much larger facility and has again begun producing soft corals and captive-reared anemones for the aquarium trade.

### *South Pacific*

Techniques used for coral culture in both the Solomon Islands and Fiji are similar, since both areas received training in the techniques by the same federal agency (United States Agency for International Development). In the Solomon Islands, this has been carried the furthest and there are now several small facilities where locals are producing several thousand fragments per month for export to the North American market (D. Palmer, fish exporter, Honiarra, Solomon Islands, pers. comm.). Small colonies of branching corals, mainly *Acropora*, *Seriatopora*, *Stylophora* and *Montipora* are selected from the reef and fragmented. These fragments are tied to small plugs of concrete with fishing line and the plugs are placed on raised sections of rebar cages and placed in sandy areas close to shore at depths of 2–6 m. After approximately six months, the plugs are harvested and shipped to North America via Fiji. Similar operations are now underway in several villages in Fiji, however wild collected colonies are still the main export from this country (A. Kirby-Bouwden, USAID, pers. comm.). It is reasonable to expect though, that cultured coral exports will surpass wild collected colony exports, at least of branching stony corals, in the next few years.

### *North America*

In addition to Tropicorium Inc., mentioned previously, there are several small-scale operations in the United States and Canada. There is some debate whether land-based facilities in northern climes can be profitable given the high cost of lighting, heating and/or cooling closed systems. There have recently been two permits granted to hold non-native corals provided by the Waikiki Aquarium for propagation by two companies in the state of Hawaii. Given its location, availability of natural sunlight at tropical intensities, and abundant seawater, Hawaii would be an ideal location for coral farming. However, the strict permitting system (involving several government agencies and review panels) and other restrictions imposed by the state, currently make such operations difficult to begin.

### *Other regions*

There are numerous start-up companies looking to begin coral aquaculture facilities in countries such as Sri Lanka, Australia, Taiwan, and Thailand, and it is only a matter of time before operations appear in all these countries. What remains to be seen is how present and future companies will deal with the various regulations and permits required by both local and foreign governments, so that they can be both successful and profitable.

### *Public displays*

Public aquariums, through their conservation ethic, have a responsibility to both educate the public and set an example when it comes to displaying live corals. As a result, several public aquariums in North America have followed the example of the Waikiki Aquarium and have begun to develop their own coral propagation programs. Currently, in addition to the Waikiki Aquarium, the Pittsburgh Aqua Zoo (who maintain over 150 species of stony coral), the Columbus Zoo and Aquarium (10 species of stony coral), and the Long Beach Aquarium of the Pacific (12 species of stony coral) have active coral propagation facilities. The Florida Aquarium recently received a \$20,000 USD grant from the American Zoo and Aquarium Association (AZA) to construct a Caribbean coral propagation facility. In Europe, the Monaco Aquarium propagates corals for research and to stock their displays, and numerous other aquaria in Italy, Portugal, and Germany are also actively propagating corals. In Japan, Tokyo Sealife Park has begun to propagate live coral from its display and is exploring supplying other aquariums in Japan with fragments (H. Arai, Tokyo Sealife Park, Tokyo, Japan, pers. comm.).

The potential for coral propagation and research by public aquariums is tremendous. Since 1997 the Waikiki Aquarium alone shipped out over 1200 pieces of coral to other institutions and coral researchers in the United States (unpubl. data). The Columbus Zoo distributed 300 fragments to other AZA institutions in 1998, and the Pittsburgh Aqua Zoo reports over 1000 fragments being distributed in 1998 to other public aquaria and local businesses (M. Brittsan, Columbus Zoo and Aquarium, Columbus, Ohio, USA, pers. comm.; J. Prappas, Pittsburgh AquaZoo, Pittsburgh, PA, USA, pers. comm.).

### *What does the future hold?*

Despite the increase in captive coral propagation for the aquarium trade in the last few years it is obvious that the industry is only at the earliest stages of development. To meet current demand for live coral many new and larger facilities must come on-line. This will require not only expertise in coral culture but also skills in assessing the needs of the market. By nature, most marine aquarium hobbyists are a discriminating group, and this often requires that corals offered for sale must meet certain requirements. Size, price, color and shape all play a role in decision making when it comes to live coral purchases. Of these, color is by far the most important. Coral farms that can provide not only a variety of species, but also a variety of the most colorful blue, green, purple, and pink species stand the best chance of market penetration and gaining the largest share of that market. Even with the success of fragmenting, most farms today are hoping to be capable of producing tens of thousands of fragments per year. It can take anywhere from two to five years to grow fragments to a size large enough to yield enough pieces to be commercially viable. At present, all of the operations providing coral fragments to the hobby do so by removing branches from large mother colonies located on the reef. In some cases, small colonies are taken and completely fragmented to

produce salable product grown on pebbles/concrete discs. Clearly, if coral farms are to increase production they must either find more mother colonies or grow their own in the equivalent of 'fields' close to shore. Although this may be viable, in some areas such fields are extremely vulnerable to predation, siltation, typhoons, increased water temperatures, boat groundings, chemical spills and poaching.

There is no doubt that fragmentation is one of the easiest techniques to introduce at the village level, and certainly it has been shown by programs in the Solomon Islands and the Philippines, that this method is commercially viable. However, not all of the coral species desired in the trade can be easily produced in large numbers via fragmentation, as can the branching corals like *Acropora*. Among these are some of the most commonly imported genera such as *Catalaphyllia*, *Euphyllia*, *Heliopungia*, *Lobophyllia* and *Trachyphyllia*. These are the so-called 'large polyped stonies' (LPS) so named for their large, showy polyps (Green and Shirley, 1999). In order for coral farms to be able to produce large quantities of not only branching corals but also LPS corals, fragmentation programs must be supplemented by other techniques. Despite the potentially large number of pieces that can be produced per year via fragmentation, this pales in comparison to the hundreds of thousands of small coral colonies that could be produced via sexual reproduction. The potential of sexual reproduction to produce seed colonies not only for the marine hobby, but also for conservation and reef restoration projects is impressive (Rinkevich, 1995). In most published cases, the methodologies employed for anthozoan mariculture are relatively simple since within the Cnidaria food specialists are rare, and most reef dwelling cnidarians reared in aquaria are symbiotic organisms (J.C. Delbeek, Waikiki Aquarium, Honolulu, USA, pers. obs.). Aspects of developmental phases, sexual reproductive modes and seasonalities, morphological differentiations, and different life history parameters of many anthozoans are well studied and available in the literature (Gateño *et al.*, 1999). This amassed information can now be used to establish defined, controlled experiments to improve and facilitate culture conditions in order that high numbers of reef dwelling invertebrates can be successfully reared in aquaria (Gateño *et al.*, 1999).

At the Great Barrier Reef Aquarium in Townsville, Australia, work has been undertaken on sexual recruitment of *Acropora formosa* (Dana) in closed systems (Hough, 1996). Taking advantage of the annual spawning of corals on the Great Barrier Reef, collection devices are placed over large mother colonies on the reef a day or so before spawning is expected. Once the corals spawn, the resulting egg/sperm bundles are removed from the collectors and the eggs are separated from the sperm. Smaller mature colonies can also be brought into the lab and allowed to spawn, and are then returned to the reef and cemented into place. Once the culturing is completed at about two months after fertilization, the four to ten polyp colonies are counted and then moved either to satellite aquaria or to reefs off Townsville so that growth and survival rates can be compared between ocean and aquarium colonies. Since 1993, several thousand colonies have been seeded. Three cyclones and several floods have reduced the effort to only one site at Magnetic Island where twenty-four, four-year old colonies are grown on large PVC trays

anchored with concrete blocks. They have spawned each year but only to a limited extent. The results of this work show that *ex-situ* fertilization rates are 90–100% using these methods, 50% survive to the planula stage of which approximately 20% die before settling. Of those that settle, about 10% metamorphose and grow. The culturing of corals in this manner could probably be much improved with the use of flow-through systems and aggressive algae control (P. Hough, Great Barrier Reef Aquarium, Townsville, Australia, pers. comm.). If these newly metamorphosed polyps are protected from predation, sedimentation and scouring, 8% survive to one year of age and 7% survive to two years. After this point no further protection is needed. See Hough (1996) for a detailed description of culturing techniques.

Preliminary work of a similar nature has also been conducted in the Red Sea using the soft corals *Clavularia hamra* (Gohar), *Nephthea* sp., and *Litophyton arboreum* (Forskäl) (Gateño *et al.*, 1999). Survivorship of settled planulae past 200 days ranged from a high of 30% for *L. arboreum* and a low of 17% for *C. hamra* and *Nephthea*. Survivorship of these species was much higher than that recorded on the reef and this could be even further enhanced if species-specific rearing conditions were provided (Gateño *et al.*, 1999).

Although much of the attention so far has been focused on corals, as Gateño *et al.* (1999) have pointed out, much is known about the reproductive habits of other cnidarians too. Some of this knowledge, however, is only coming to light through the efforts of coral culturists in the field. For example, Larry Sharron of Belau Aquaculture has discovered the cues that are necessary to stimulate male anemones *Stichodactyla mertensii* (Brandt) to release sperm (L. Sharron, Belau Aquaculture, pers. comm.). In his culture systems, males are stimulated to release sperm and females downstream from the males then take this sperm internally to fertilize their gametes. Young are brooded internally then ejected out through the mouth where they float downstream and attach to loose aggregate. These discoveries, which remain undisclosed for commercial reasons, are of significance because they allow the production of large numbers of offspring, thereby obviating the need to collect wild-caught specimens to supply the aquarium trade. It is also significant in that this species is a notoriously poor shipper, often arriving in such poor condition that they usually succumb to bacterial infections and die shortly after arrival (J. Sprung, advanced aquarium hobbyist, USA, pers. comm.). Recently, four young *S. mertensii* were shipped to the Waikiki Aquarium and after three months appeared healthy and are growing rapidly.

The use of *ex-situ* sexual reproduction is undeniably the direction in which coral culture is headed. Aside from the obvious advantage over fragmentation offered by the production of hundreds of thousands of offspring in a single spawning event, the fact that mother colonies are left undisturbed or at worst temporarily removed from the reef, argues in favor of the environmental benefits of this method. Sexual reproduction may also allow for the large-scale cultivation of LPS corals, which are generally considered much more difficult to produce in numbers through fragmentation. The rapid growth rates of LPS corals such as *Euphyllia* and *Catalaphyllia*

(see Green and Shirley, 1999) argue for the ease with which these could then be brought to market.

Finally, the majority of attention in the marine reef aquarium hobby has so far been focused on those species that contain zooxanthellae due to their ease of maintenance. However, there are a large number of azooxanthellate anthozoans that would also make wonderful aquarium subjects. Non-photosynthetic soft corals such as *Dendronephthya*, *Scleronephthya* and *Stereonephthya* can also be easily produced via fragmentation (J.C. Delbeek, Waikiki Aquarium, Honolulu, HI, USA, pers. obs.; Fabricus *et al.*, 1995). Other corals such as some of the antipatharian species (e.g. *Cirripathes*, Wire Coral) grow rapidly on a diet of live *Artemia salina*, and can be easily propagated via cuttings (J.C. Delbeek, Waikiki Aquarium, Honolulu, HI, USA, pers. obs.). In Japan, it is not unusual to see aquaria devoted entirely to deeper-water fishes and azooxanthellate corals. These displays can be just as colorful and interesting as traditional reef aquaria.

This is an exciting time in the history of the marine aquarium industry. We are on the verge of several breakthroughs in understanding the husbandry of live corals and their reproduction. Hopefully this will help to ensure that the aquarium hobby and the marine ornamental industry continue through the 21st century.

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